Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Early warning platform and its potential for non-coal mine goaf monitoring based on an optical fiber sensing network

To cite this article: Zengrong Sun *et al* 2018 *J. Phys.: Conf. Ser.* **1065** 252018

IOP Conf. Series: Journal of Physics: Conf. Series **1065** (2018) 252018 doi:10.1088/1742-6596/1065/25/252018

Early warning platform and its potential for non-coal mine goaf monitoring based on an optical fiber sensing network

Zengrong Sun[1], Tongyu Liu[2], Guangdong Song[2,4*], Binxin Hu[2], Long Jiang[3], Zenghua Sun[1], Qi Wu[1], Tong Sun[5] and Kenneth T V Grattan[5]

[1] Shandong Shenglong Safe Technology Co., Ltd, Jinan 250032, China

[2] Laser Institute, Qilu University of Technology (Shandong Academy of Sciences), Jinan, Shandong 250014, China

[3] Shangdong Micro-sensor Photonics Limited, Jinan 250014, China

[4] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining & Technology, Beijing 100083, China

5 School of Mathematics, Computer Science and Engineering, City, University of London, London, EC1V 0HB, United Kingdom

*Email:guangdongsgd@163.com

Abstract: Remote monitoring of a mine goaf (defined as that part of the mine from which the mineral deposit has been wholly or partially removed) is challenging, to create an early warning of potential mine collapse. In this paper, optical fiber sensing technology is applied to setting up a monitoring network and from it, through data collection and analysis, an early warning platform can be developed. When the monitoring data are collected, an analysis of dynamic disaster theory is used and the potential for the occurrence of collapse potentially can be determined. This approach provides an important means to predict sudden collapse and avoid loss of life and property in the mined-out area underground. Typical field data produced show that the monitoring results mirror the actual situation seen in mines in China, showing the value of optical fiber sensing technology for accurate monitoring of mined out areas of such workings.

1. Introduction

Although China is a country rich in mineral resources, there are a great number of untreated goaves (defined as those parts of a mine from which the mineral sought has been wholly or partially removed) for various reasons, be they economic, technological and historical, and these are causing concerns. In particular, up to the 1980s, there was a lot of illegal and unplanned mining which has left a large number of such goaves, in unrecorded locations, which affect the production and safety of current mines and thus valuable mineral resources may be untapped. A large area of such 'mined out' land, retained by mine enterprises, is one of the three most dangerous mine hazards today due to accidents caused by the sudden falling in of goafs [1-3].

This problem needs to be tackled and optical fiber sensing offers a particular solution which is well suited to today's mining needs. The technology is multidisciplinary and relatively mature for measuring temperature, pressure, strain, vibration, ultrasound and other physical quantities [4], offering high sensitivity and strong electromagnetic interference resistance. Its characteristics suit mining needs well as the fiber itself is small in volume, light in mass, easy to bend, passive, corrosion resistant and not electrical in nature, thereby minimizing potential explosion hazards [5]. This technology has been widely applied in applications which range from the military, through commercial engineering needs, including perimeter security and electric power field monitoring, for example [6]. However, applications in goaf monitoring of mine workings are relatively few but by their nature well suited to optical fiber-based technology.

This paper introduces the application of innovative optical fiber sensing technology in goaf monitoring of mine workings. An appropriate data analysis platform has been developed to allow the processing of the data collected from a large number of optical fiber sensors of different types in this environment. Such sensors will be shown to have potential to be used in the prediction and thus early warning of collapse of mine workings: creating data that can be interpreted, allowing better safety predictions before the wider spread of damage to the surface.

2. Optical fiber sensing network

In order to observe the changes in the overlying rock mass of a goaf, the monitoring base point is usually set up on the surface, above the goaf itself. The main solution to eliminating a goaf is to fill it in [7-9], but circumstances are such that many goaves are unknown in location or inaccessible and thus cannot readily be filled in. Thus potentially a large unfilled area can occur, which then constitutes a hidden danger of sudden collapse. While conventional ground base point measurements can readily show the results of a goaf collapse, nevertheless, such a technique cannot give early warning or indeed early prediction of a goaf collapse. Optical fiber sensing monitoring technology allows several measuring points to be set up deep underground and a monitoring system network created in that region. Sensors in different regions can be used in parallel, allowing detailed information on the active state of the deep rock mass to be obtained as a result of the data collected from multiple points.

In this work, optical fiber displacement, stress and microseismic monitoring systems are developed and adopted for active goaf monitoring. Optical fiber displacement and stress monitoring is used and a system created to do so is composed of optical fiber displacement and stress sensors together with a fiber grating demodulator, a connecting optical cable, dedicated system software, and appropriate installation accessories. Stress and displacement changes in the rock mass will induce displacement and stresses, monitored by these sensors. The wavelength change of a Fiber Bragg Grating (FBG) serves as the main transduction mechanism in these sensors and the measurements recorded at the fiber grating demodulation interrogation system are analyzed and from that data are calculated, allowing real-time measurement value of stress and displacement of the rock mass to be obtained.

The interrogation substations for the Fiber Bragg Grating sensors are individually connected to the Ethernet ring network, allowing the data collected to be sent for analysis and processing in the cloud server.

3. Monitoring and early warning platform

3.1. Platform characteristic

The field monitoring system created allows data acquisition, data temporary storage and data uploading to occur and the data service platform allows data storage, data query, statistical analysis, operation calculation, situation analysis, real-time warning, result push, equipment management and other functions to be performed. The specific characteristics of the system are as follows:

- There is a unified data standard, unified access and unified management of equipment;
- It is convenient for users to use and allows government supervision;
- It has a high level of compatibility and openness and thus expansibility as the need arises;
- It has a reserved interface to adapt to the deployment of multiple monitoring services.

3.2. Early warning algorithm

The period of collapse from inception to spread to the surface can be calculated by monitoring the relative change of the deep base point and shallow base point of the mine. The sensor installation is shown in Figure 1. The detailed algorithm describing this situation is as follows:

$$\mathrm{V} = (L_2 - L_1)/T_1$$

$$T_2 = (L_1 - L_0) \times V$$

where V is the velocity of the relative displacement of the strata, L_2 is burial depth of the deep base point, L_1 is burial depth of the shallow base point, T_1 is the trigger time difference between the shallow base point and the deep base point, T_2 is the period of collapse from the trigger time of the shallow base point to the point where the surface begins to change and L_0 is the elevation.

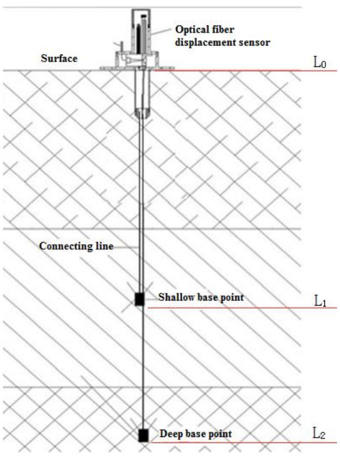

Figure 1. Schematic diagram of the installation of the optical fiber displacement sensors used

Figure 2. Schematic diagram of the layout of the goaves in the 13 gypsum mines considered

4. Field application of the monitoring technique

There are 13 gypsum mines in Pingyi County, Linyi City, Shandong Province. The total area of these gypsum mines is 2902686m^2, while the area of the more unstable goaf present is 1494616m^2 (and which accounts for >50% of the total area assessed).

The surrounding environmental conditions of the goaf are complex and the layout of the monitoring points in the goaf should be specially tailored to the situation in a particular mine. The advantages of the monitoring methods described can be fully utilized, given the conditions of the surrounding surface of the goaf, how stable the situation is and the characteristics of the monitoring system that are adopted. The location, configuration and number of the sensors used in the mined-out area of Pingyi County have been tailored for each individual mine, where the sensor system comprises 6 monitoring units with 310 measuring points and 155 optical fiber sensors installed. A schematic diagram of sensor layout is shown in Figure 2 and the changing trend of rock mass displacement is shown in Figure 3. This figure shows displacement value of the monitoring point for one month, the results showing that there is no displacement change.

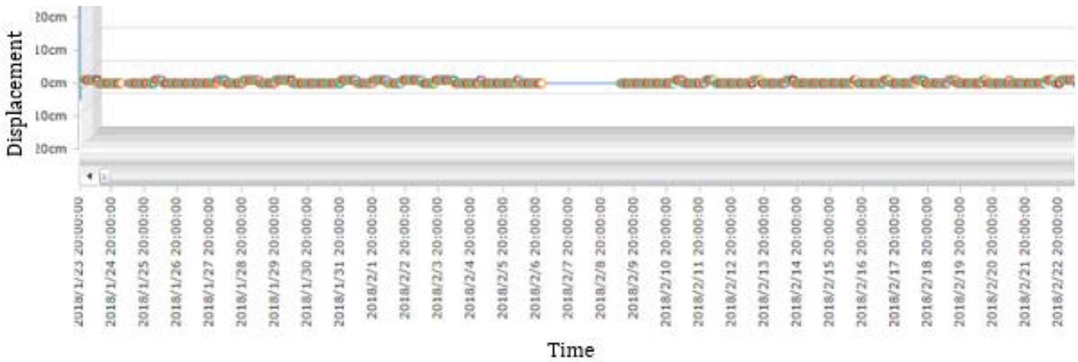

Figure 3. Changing trend of rock mass displacement at the chosen monitoring point

5. Conclusion

The work has shown that optical fiber sensing technology can be applied to monitoring the geological conditions in mines, and in particular goafs in non-coal mines. There is clearly scope for wider applications of the fiber optic monitoring techniques discussed and thus obtaining more data than can then be used for predictive monitoring. The combination of data monitoring, an early warning platform and the use of an optical fiber sensor network facilitates obtaining real-time information on the state of the goaf in the non-coal mine, allowing its better management and promoting greater safety. All this greatly reduces the hazards to users and ultimately the losses of life and property caused by the collapse of the goaf. Work is continuing to explore these monitoring techniques further.

References

[1] Jia H B, Ren F Y, Ding H X and He R X 2018 *Metal Mine* **47** 41-45

[2] Li L *2012 XI'AN UNIVERSITY OF ARCHITECTURE AND TECHNOLOGY* (Xi'an)

[3] Zou D Y, Zhang G W, Xin C P and Zhang M H 2009 *Coal Science and Technology* **37** 53-56

[4] Wang C, Wang Y H, Zhang N B, He Z T, Zhou Z and Ma L Z 2008 *SHANDONG SCIENCE* **21** 9-12

[5] Song G D, Wang X, Liu T Y, Wang C, Wang J Y, Qi H F and Ni J S 2012 *SAFETY in COAL MINES* 55-57

[6] Hou J F, Pei L, Li Z X and Liu C 2012 *ELECTRO-OPTIC TECHNOLOGY APPLICATION* **27** 49-53

[7] Xu B G, Wang C L, Tang S H and Luo C 2007 *China Safety Science Journal* **17** 147-152

[8] Ge W Q 2004 *ENERGY OF CHINA* **26** 27-30

[9] Wang H, Yang W M, Wang B and Zhao C Z 2008 *COAL ENGINEERING* 119-123